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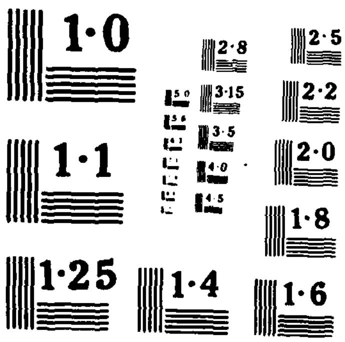
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OPTIMIZING PERSONNEL ASSIGNMENT IN THE NAVY: THE SEAMAN, FIREMAN, AND AIRMAN APPLICATION

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OPTIMIZING PERSONNEL ASSIGNMENT IN THE NAVY: THE SEAMAN, FIREMAN, AND AIRMAN APPLICATION

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We have developed an assignment optimization model for seaman, fireman, and airman personnel. This model is a large-scale capacitated network. We have integrated four allocation, seven assignments, and numerous person/job eligibility criteria into the model. The model efficiently matches personnel to jobs; and the model effectively executes assignment policy.

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FOREWORD

This report was prepared as part of work units ZF66-512-001.013 (Multiple-Criterion Optimization Techniques) and Z1770-MP006 (Personnel Assignment Systems). The objective of these projects is to develop computer-based models to improve the Navy's personnel assignment system.

This report is the third in a series resulting from these projects. Previous reports described a heuristic approach for developing aggregate numerical allocation goals for enlisted personnel assignment (NPRDC TR 84-41) and a network formulation to solve the Navy's personnel assignment problem (NPRDC TR 84-49). This report documents the development of an automated model for Seaman (SN).

The SN assignment model has been accepted by the Enlisted Personnel Management Center (EPMAC), New Orleans, and is being implemented for all general detail recruits: Seaman, Fireman, and Airman. The Naval Military Personnel Command is sponsoring efforts to develop similar models for rated personnel.

We acknowledge the support and advice of CAPT T. Shope, OP-135, formerly EPMAC-00, LCDR G. Habel, OP-01B2, formerly NMPC-451, Mr. F. Ritter, formerly EPMAC-30, and CDR J. Varley, formerly EPMAC-40.

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Technical Director

SUMMARY

Problem

Navy personnel assignment is a large, complex operation. Under the current manual system, it is not possible to simultaneously consider all feasible person/job combinations and the multiple, conflicting policies that guide the assignment process. The detailer directory in Link (1986) magazine list 16 detailers who current~~ly handle Sea~~man, Fireman, and Airman assignment. An automated assignment model is needed to improve the efficiency and effectiveness of the personnel assignment system. However, the complexity of eligibility and policy criteria combined with the necessity of including aggregate numerical allocation goals make modeling efforts difficult. Furthermore, an acceptable automated assignment model must solve a large-scale, multiple objective optimization problem with an integer solution within reasonable time and cost limits.

Objective

The objective of this research was to develop an automated assignment model for Seaman (SN) personnel.

Approach

A large-scale capacitated network model was developed integrating four allocation policies, seven assignment policies, and numerous person/job eligibility criteria for the SN rating. The formulation allows use of commercially available network computer codes for solving the network model.

Results and Discussion

Computational results show that the model can process an average week's workload for SN general detailed (GENDET) assignments (about 250 people) in less than 20 minutes of central processing unit (CPU) time on an IBM 4341/12 computer. This means an efficient method for matching personnel to jobs has been developed. Also, the model provides an effective method for assignment policy execution. In addition, use of this model will allow extra time for detailers to handle special cases.

The Enlisted Personnel Management Center (EPMAC) has accepted the SN assignment model. Since the assignment criteria are similar for all non-rated GENDET recruits, the model is being implemented at EPMAC for Seaman, Fireman, and Airman recruits.

Future Developments

Future plans include expanding the model to solve the personnel assignment problem for skilled enlisted communities. A prototype model has already been developed for the administrative, deck, and supply ratings using the same optimization technology. We are also developing new technologies to solve personnel assignment problems for ratings that require extensive technical training and contain multiple skills.

CONTENTS

INTRODUCTION

Background

Every day a large number of Navy personnel become available for new assignments and a large number of job vacancies are created. Personnel are scheduled to rotate from one job to another and from one region to another, with every rotation action creating a job vacancy that needs to be filled. In addition, many personnel leave the Navy, creating additional job vacancies. Also, after new personnel receive training from schools, they become assets for assignment. These assignments are made by the wholesale allocation of personnel via quotas to major Navy units distinguished by region, type of duty, etc., followed by the assignment or "detail" of individuals to jobs within those unit groups.

Navy personnel assignment is basically a manual process. Deficiencies in this process include (1) the lack of efficiency in terms of time and cost, (2) the inability to identify all possible choices and select the best one, and perhaps most serious, (3) the inability to execute multiple assignment policies properly. The Navy has been concerned about deficiencies in the manual process and has devoted substantial efforts to computerize personnel and job data files. Although these efforts have resulted in various data retrieval systems that make information more accessible to assignment managers, use of these systems has not changed the fundamental personnel assignment process. The Navy is still assigning people to jobs manually every day.

Problem

The assignment manager, or detailer, must consider if a person is eligible for a particular job, and also whether alternative assignments would better satisfy the Navy's and the individual's needs. The person/job matching process presents a problem with a very large number of choices. For example, with only three individuals and five jobs, there are 60[1] possible sets of assignments. The number of person/job matches increases exponentially, so that there are over a million possible matches with only 7 persons and 11 jobs.

Starting with printouts of personnel records and jobs, the detailer must first determine all the possible choices and then select the best matches among all the possible alternatives, while considering the relative importance of various policy criteria. Under normal time constraints, it is not humanly possible to consider all feasible person/job combinations and the dozen or so policy criteria simultaneously. The need for an automated personnel assignment model then becomes clear.

To develop an assignment model, it is necessary to quantify information about individuals and policies. This information includes numerous and sometimes conflicting rules, regulations, and policy objectives. In addition, frequently changing numerical allocation goals must be integrated in the personnel assignment model. An acceptable assignment model must solve a large-scale, multiple objective optimization problem with an integer solution, and within reasonable time and cost limits.

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[1] For an assignment problem with m people and n jobs, the total number of possible assignments, T, is:

$T = n!/(n-m)!$ for $n \geq m$.

There have been previous attempts to develop operational military personnel assignment models. These are discussed in Appendix A.

Objective

The objective of this effort was to develop an automated assignment model for Navy enlisted personnel. The group of personnel called seaman (SN) was selected for initial model development.

APPROACH

Development Strategy

We chose the SN group to develop the initial automated assignment model for three reasons. First, it is one of the non-rated enlisted occupations in the Navy. Modeling of eligibility and policy criteria is the most straightforward for non-rated personnel. The SN model does not have to consider pay grade substitution, advanced training, or multiple skill requirements. Second, the SN rating is the largest occupational group in the Navy with a population of about 50,000. The Navy assigns about 1,500 SN personnel every month. Third, assignment managers at the Enlisted Personnel Management Center (EPMAC), New Orleans[2] were interested in participating in the model's development.

Data Structure

The SN group includes three pay grades: E-1, E-2, and E-3. The duties of a seaman are to keep compartments, lines, rigging, decks, and deck machinery shipshape, and serve as lookouts, members of gun crews, helmsmen, and security and fire sentries. Approximately three-fourths of all SN assignments are for general detail (GENDET) recruits, right out of boot camp. The rest of the SNs are personnel who become immediately available for assignment (e.g., school dropouts) and personnel who need to be rotated from other jobs. GENDET data is used as a base to develop the model for the SN rating.

Table 1 lists personnel and job information that needs to be considered in the SN assignment decision. These data are used for determining person/job eligibility and "costs" of assigning a given person to a given job.

Fleet summary data are also needed to develop the numerical allocation goals. This data represents aggregations over individual personnel and jobs, and includes billets, personnel, and personnel shortages by composite. Composites are defined by sex, Chief of Naval Operations (CNO) priority, type duty (sea/shore), and Manning Control Authority (MCA).[3]

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[2]EPMAC assigns all non-rated personnel in the Navy. The Naval Military Personnel Command assigns rated or skilled personnel.

[3]There are three MCAs: Commander-in-Chief, U.S. Pacific Fleet; Commander-in-Chief, U.S. Atlantic Fleet; and Commander, Naval Military Personnel Command.

Table 1

Personnel and Job Information to Consider in Assignment Decision

Personnel Information	Job Information
1. Name	1. Pay grade requirement
2. Social Security Number	2. Skill requirement
3. Pay grade	3. Location
4. Date of availability	4. Job vacancy date
5. Class of availability	5. Requisition priority
6. Current assignment	6. CNO priority
7. Locational preferences	7. Sex restrictions
8. Sex	8. Sex/shore code
9. Number of dependents	9. Manning control availability
10. U.S. citizenship	10. Special qualifiers
11. Security clearance	11. Nuclear powered ship
12. Overseas qualifications	12. Reserve ship
13. New construction qualifications	13. Ship type
14. Coast guarantee	
15. Membership in buddy program	
16. Duty with relative or spouse guarantee	
17. Current assignment location	

Eligibility Criteria

Person/job eligibility criteria govern whether or not an individual can be assigned to a specific job. Eligibility is expressed, for a given person and job, as either yes or no. For example, females are not eligible to be assigned to combatant ships. Criteria that can be expressed as preferences are called allocation or assignment policies and are discussed in the following sections.

The eligibility criteria for the SN assignment model are as follows:

1. Jobs are classified as male only, female only, or mixed. Mixed jobs can be filled by males or females.

2. Personnel can have Pacific or Atlantic coast guarantees.

3. Some personnel are not qualified for overseas duty.

4. People who are not U.S. citizens are not eligible for overseas shore duty or for duty on a nuclear powered ship.

5. Reserve personnel are only eligible for sea duty.

6. Personnel with dependents are not eligible for overseas duty.

These criteria only apply to SN, fireman (FN), and airman (AN) GENDETS.

In addition to the above, some jobs have a 3-digit code that corresponds to a specific eligibility criteria for that job. There are over 700 of these codes. Examples of these criteria are that the person must be (1) overseas qualified, (2) a U.S. citizen, or (3) must not report for duty earlier than the job vacancy date.

Assignment Policies

Policies defined for an individual person/job match that can be expressed as preferences are called assignment policies. For example, the Navy prefers to send reserve personnel to reserve ships, but if no jobs are open on reserve ships, reserve personnel can be assigned to other ships. EPMAC wanted seven assignment policies of this nature included in the SN assignment model.

The assignment policies are:

1. Meet individual location preference.

2. Minimize moving distance.

3. Fill jobs in requisition (fleet's request to fill job vacancy) priority order.

4. Assign reserve personnel to reserve ships.

5. Fill jobs by vacancy date, early dates first.

6. Fill jobs by vacancy date group (i.e., all vacancies within four months).

7. Minimize difference between personnel availability date and job vacancy date.

These multiple conflicting policies make it difficult, if not impossible, for the detailers to make effective and efficient assignment decisions over the entire range of individual personnel and jobs. Because of the sheer volume of information, the possible trade-offs among policies are often unknown.

Allocation Policies

Allocation policies are designed to distribute people through the assignment process to achieve certain levels of collective goals. These goals are measured by manning, which is defined as the percent of authorized billets that are filled.

There are four allocation policies:

1. CNO priority.
2. Sex.
3. Duty type.
4. MCA.

The first policy is to fill all CNO priority jobs. Shortages of personnel in this category are determined at the activity level. The second policy is allocation by sex. Jobs are classified as male, female, or mixed. Current policy is to fill all male jobs and all female jobs before filling any mixed jobs. The third policy is allocation by duty type. For male only jobs, shore duty is filled first, followed by sea duty, because there are few shore jobs in the male only category. For female only jobs, sea duty is filled first, followed by shore duty. The fourth policy is allocation by MCA. Equal manning levels by MCA (i.e., fleet balance) is the goal.

Model Formulation

Seaman assignment is modeled as a network flow model. Eligibility, assignment, and allocation criteria were integrated into a single network model. In this way, the model can consider all feasible person/job combinations and optimize all assignment and allocation policies simultaneously. A complete description of the network formulation is in Appendix B.

When quantifying policies, we attempt to convert each policy into a small number of discrete values (see Appendix C for details). This accomplishes two objectives. First, smaller weights can be used when summing the policies, while maintaining preemptive ordering (see next section). These smaller weights allow more policies to fit in a given amount of computer storage. Second, this allows some trade-offs for less important policies to be improved. Also, a constant added to or multiplied by all values of a policy will not affect the optimal solution.

We realize that any scoring of policies implies certain trade-offs. although analytic justification for the values used is lacking, the model has proved superior to the present manual system and has been accepted for implementation. More research into the question of scoring policies could be beneficial.

Relative Importance of Policies

The current implementation of the model at EPMAC ranks the relative importance of policies as follows:

1. Eligibility.
2. Allocation policies (order specified by user).
3. Maximum assignment of personnel.
4. Assignment policies (order specified by user).

Person/job eligibility criteria are always the most important. If a person is not eligible for a job, the model will never nominate the person for that job. Next most important are the four allocation policies previously described. Any ordering or subset of these policies can be specified by the user. The third most important policy is maximum assignment of personnel. Maximum assignment of personnel is an implicit policy in the model. Within the eligibility criteria and flow constraints or capacities, the model will attempt to assign

everyone. Fourth most important are the seven assignment policies. Like allocation, any ordering or subset of these policies can be specified by the user.

Allocation policies are currently modeled as constraints to assignment. If the allocation goals cannot be met, people are left unassigned. User options exist in the model to treat allocation in a more flexible manner. This has the effect of making maximum assignment of personnel the number two level policy and allocation policies number three.

When allocation policies are allowed to be flexible, there is no need to have all allocation policies more important than all assignment policies. The four allocation policies and the seven assignment policies could be interspersed in any manner.

It should be noted that some kinds of policies can be alternatively treated as eligibility rules, allocation criteria, or assignment policies. For example, CNO priorities are handled by an allocation policy that specifies 100 percent fill of CNO priority billets. These billets could also be filled using an assignment policy that specifies fill of all CNO priority jobs before non-CNO priority jobs. More commonly, a person/job match can be prevented by making the person ineligible for the job or by making an assignment policy that attaches a high cost to that person/job match.

Network Codes

Formulation of the SN assignment model, as a pure network, allows us to use widely available computer codes such as GNET (Bradley, Brown, & Graves, 1977), NETFLO (Kennington & Helgason, 1980), or SAS/OR (1983) to solve the problem. Alternatively, the assignment model can be represented as an "assignment with side constraints problem." The allocation policies represent the side constraints. Algorithms and computer codes to solve the more general pure network with side constraints problem do exist (Barr, Farhangian, & Kennington, in press; Glover, Karney, Klingman, & Russell, 1978), but these codes are not commercially available. Further research would be required to determine if they could solve the Navy's assignment problem efficiently. Also, with the addition of side constraints, we can no longer guarantee an integer solution.

Research is being conducted at the Navy Personnel Research and Development Center (NAVPERSRANDCEN) to develop algorithms and computer codes to solve the assignment with side constraints problem. If this capability is achieved, we could incorporate additional policies that cannot be modeled by a pure network. However, at this time, we believe that if the problem can be formulated as a pure network, use of a code such as GNET is the most efficient way to solve the problem.

RESULTS AND DISCUSSION

Computer software was developed to formulate the SN assignment problem as a network model, and a modified version of GNET was used to solve the optimization problem. Software was also developed for report generation. The FORTRAN language was used for all the programs. Since GNET is available in FORTRAN, using this language throughout simplifies development and maintenance.

Table 2 shows the computational results of matching 250 seamen to 400 jobs. The entire model required about 19 minutes of CPU time on an IBM 4341/12 computer. About 76 percent of the CPU time was used for model formulation, 18 percent of the time was used for model solution, and 6 percent of CPU time was used for report generation. This represents an average week's workload for SN GENDET assignments.

Table 2

Computational Results on an
IBM 4341 Model 12

Number of People	250
Number of Jobs	400
Number of Nodes	768
Number of ARCS	58,755
Number of Policies	11
Total Time (CPU seconds)	1,117
Model formulation	844
Network optimization	205
Report generation	68
Computer Core Storage (K)	
Model formulation	364
Network optimization	1,274
Report generation	294

EPMAC decided to accept and implement the automated assignment model for the SN rating after various tests and several revisions of the model formulation. Since the assignment procedure is the same for fireman and airman GENDETS, the same model is being implemented for their assignment.

We have developed a personnel assignment model for the SN rating. This model uses a network formulation to integrate person/job eligibility criteria, allocation policies, and assignment policies. Use of recent advances in network solution algorithms allows us to solve this large-scale integer problem.

This model provides an efficient and effective means for personnel assignment. It quantifies multiple goals using a preemptive solution procedure. Decision makers need only specify an ordering of goals.

FUTURE DEVELOPMENTS

Future plans include expanding the model to solve the personnel assignment problem for enlisted ratings and distributable communities. A prototype model has already been developed for the administrative, deck, and supply ratings using the same optimization technology. We are also developing new technologies to solve personnel assignment problems for ratings that require extensive technical training and contain multiple skills.

Although this report discussed the model's operational use in executing assignments, the model can also be used for policy planning and evaluation. In the policy planning mode, the user can explore the implications of varying policies. This makes it possible to evaluate the effects of alternative policy orders before a policy decision is made. Illustration of the model's policy planning and evaluation capability will be the subject of future work.

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APPENDIX A

HISTORICAL PERSPECTIVE ON AUTOMATED MILITARY PERSONNEL ASSIGNMENT

HISTORICAL PERSPECTIVE ON AUTOMATED MILITARY PERSONNEL ASSIGNMENT

In 1968, the Navy's Bureau of Personnel (BUPERS) encouraged research to increase use of the computer to improve personnel assignment in the Navy, particularly to reduce the workload of detailers in making assignment decisions. In the early 1970s, Malone, Thorpe, Tate, and Pehl (1974) developed a prototype computer-assisted distribution and assignment system (CADA), using a mathematical programming approach. Although CADA was tested on the BUPERS computer, it was never implemented. Butterworth, Gibfried, and Marshall (1975) evaluated CADA and pointed out several factors that contributed to its demise. The most detrimental factor was that it required a large amount of computer memory and time to run CADA for a small sample. In 1977, Glover, Karney, and Klingman developed a prototype model to improve the mathematical algorithm for the Navy assignment problem. Their approach required significantly less computer resources, but it was never expanded to model the operational problem.

The Air Force currently has an automated assignment system, basically a sort and match process, which was developed over a decade ago. Although a transportation model developed by Beatty (1978) was incorporated into this system, it does not appear that the multiple policies aspect of assignment has been addressed sufficiently. For the Marine Corps, Hatch, Nauta, and Pierce (1973) developed an enlisted distribution model that, like CADA, employed a mathematical programming approach with a composite multiple objective function. One problem in using this type of approach is the difficulty in quantifying macro level policies like allocation policies.

Goal programming, first defined by Charnes and Cooper (1977), is a variation of linear programming that allows for consideration of multiple and conflicting goals. However, decision makers are forced to give careful consideration to the relative importance and priority of their goals, and must use postoptimal analysis to assess the effect of changing the priorities of the multiple goals. Using goal programming, Charnes and Cooper (1984) developed a network model to study planning issues related to the Navy's sea-shore rotation problem. Klingman (1984) developed a goal programming network model to improve the Marine Corps' assignment problem. He used goal deviation variables to determine aggregate numerical allocation goals. However, the Navy's allocation problem is much more complicated than Klingman's formulation for the Marine Corps.

Without using goal deviation variables, Liang (1984) developed a theoretical model using network methodology for the Navy's assignment problem. Allocation is an integral part of this assignment model, and the work provides a foundation for developing an assignment model in accordance with all Navy policies.

APPENDIX B

NETWORK FLOW MODEL FOR SEAMAN ASSIGNMENT

NETWORK FLOW MODEL FOR SEAMAN ASSIGNMENT

A network is a collection of nodes and arcs. Each arc in the network has flow directed as specified by the arrow head of the arc. In our model, each arc is assigned two parameters: a capacity, which is the maximum amount of flow that the arc can carry; and a cost for each unit of flow that passes through the arc. The required quantities of flow entering or leaving the network at each node are also specified. Flows entering the network are often called the supply and flows leaving the network are called the demand. Flow is conserved at each node.

The flows on the arcs are controllable within the limits, or constraints, set by arc capabilities, conservation of flow, and external supply and demand. These arc flows are the decision variables of an optimization problem. The optimization problem is to choose the arc flows, within the above restrictions, to minimize total cost of the flow.

Eligibility, assignment policies, and allocation policies are combined into a single network model as shown in Figure B-1. This type of network model is called a "pure minimum cost flow model" or a "capacitated transshipment model." Flows enter the network at node 1 and leave the network at node 2. These supply and demand values are equal to the number of personnel available for assignment. Nodes 3 through 116 define the allocation policies. A complete description of how the arcs connecting these nodes and associated capacities and costs are determined is given by Liang (1984). Multiple arcs between pairs of nodes are used to model nonlinear cost functions.

Nodes 117 to n correspond to people and nodes n+2 to m correspond to jobs. If a person is eligible for a given job, there is an arc connecting the corresponding person and job node. This arc has a capacity of one and a cost based on the assignment policies. This cost is determined by quantifying each assignment policy, calculating the policy values implied by the potential assignment, and then forming a weighted sum of the policy values. The weights are defined based on the order of policies. When searching for an optimal solution, improvement in the first policy is more important than improvement in the second policy, which is more important than improvement in the third policy, etc. Using weights in this manner does not always give strictly preemptive solutions. However, the computational simplicity outweighs the use of a preemptive solution algorithm for our model.

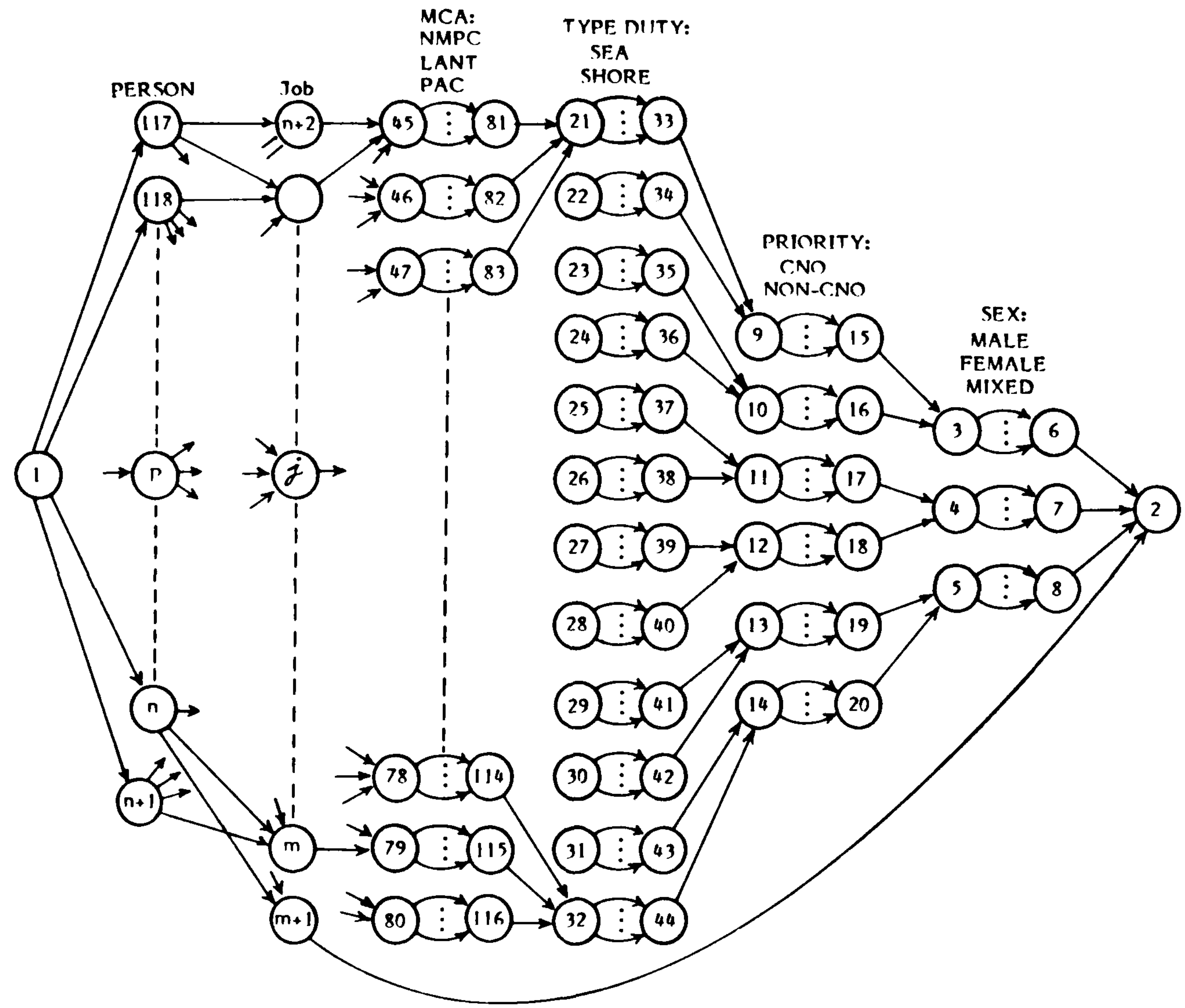

Figure B-1. Network flow model for seaman assignment.

APPENDIX C

QUANTIFICATION OF ASSIGNMENT POLICIES

QUANTIFICATION OF ASSIGNMENT POLICIES

The assignment policies are quantified in the following manner.

1. Individual Location Preference

2	if assigned to first preference
3	if assigned to same geographical area as first preference
4	if assigned to second preference
5	if assigned to same geographical area as second preference
6	if assigned to third preference
7	if assigned to same geographical area as third preference
8	if assigned to fourth preference
9	if assigned to same geographical area as fourth preference
14	if no preference is met

2. Moving Distance

Moving distance is used as a measure for permanent change of station cost. The great circle distance between locations is calculated using latitude and longitude values. This distance is transformed via the integer part of r/7.5, where r is the square root of distance. This results in fifteen groups scored as follows:

0	if	0	to	56	miles
1	if	57	to	224	miles
2	if	225	to	506	miles
3	if	507	to	899	miles
4	if	900	to	1,406	miles
5	if	1,407	to	2,024	miles
6	if	2,025	to	2,756	miles
7	if	2,757	to	3,599	miles
8	if	3,600	to	4,556	miles
9	if	4,557	to	5,624	miles
10	if	5,625	to	6,806	miles
11	if	6,807	to	8,099	miles
12	if	8,100	to	9,506	miles
13	if	9,507	to	11,024	miles
14	if over			11,024	miles

3. Requisition Priority

The eight digit requisition number is used to define requisition priority. The first four digits are the requisition file date. The next three digits are the requisition priority. This value is used, untransformed, to quantify the requisition priority policy. The last digit of the requisition number is a special qualifier, that is not used.

4. Naval Reserve

The reserve personnel policy is scored as follows.

0	if reserve person and reserve ship
1	otherwise

5. Job Vacancy Date

There are two policies defined on job vacancy date. This date is usually referred to as take-up month. The first policy groups jobs by vacancy date:

0 if the job vacancy date is within four months of the present date
1 otherwise.

The second vacancy date policy is defined as $12y + m$, where y is the year and m is the month of job vacancy.

6. Difference between Avail Date and Vacancy Date

The difference between personnel availability date and job vacancy date is defined by

$$|(12y1 + m1) - (12y2 + m2)|$$

where $y1$ is the year and $m1$ the month of person availability and $y2$ is the year and $m2$ the month of job vacancy.

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